Renewable and Sustainable Energy Reviews 37 (2014) 734–749

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Dust effect on photovoltaic utilization in Iraq: Review article

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ARTICLE INFO

Article history:
Received 19 November 2013
Received in revised form
13 May 2014
Accepted 20 May 2014
Available online 10 June 2014

Keywords:
Photovoltaic
Solar energy
Dust
Pollutants
Iraq

ABSTRACT

The term Dust is called for any substance that spreads in the air which includes soil and dust particles (suspended dust), smoke, fog and particulate matters. It is formed from organic and inorganic substances of terrestrial origin. Such substances are like sand storms, factory smoke, bacteria, pollen, Forrest fires and volcanoes vapors. Also, they include solid atmospheric particles that stay suspended in the air for long periods, and that are able to move with wind movements for long distances. It represents large differences in volume, shape, distribution and concentrations. Dust-storms are an environmental phenomenon that transcends boundaries and their growing intensity and frequency-as a result of increasing desertification and decreasing vegetation coverage-has a tremendous negative impact on national and regional human and socio-economic development.

In this study, a review of Iraqi geographical and meteorically characteristics will be made. In addition, a review of the human activities that increased desertification in Iraq areas that reflects on increasing sand and dust storms in the country will also be reviewed. The focus on dust causes, types and specifications was a priority in order to analyze its effects on PV systems. PV systems performance is affected by dust and dust storms highly influence the energy collected. A comprehensive review for the effect of dust on PV in Iraq is represented to researchers; designers and engineers dealing with PV systems in Iraq.

Contents

1. Introduction

Marten Cobler the representative of Secretary General of the UN in Iraq said in his word in Nairobi Conference about the environment on 21st February 2013 that Iraq faced 122 sand-dust storms and it is expected that Iraq will face 300 storms per year within the next five years. “Environmental issues impact everyone in Iraq. Dust storms, desertification and water scarcity are only three of many pressing issues”, said Martin Cobler. Addressing these challenges has to start with each of us [1].

Iraq suffered from nearly a decade of war and two decades of drought, a new dust bowl appears to be forming. Chronically plagued by overgrazing and over plowing, Iraq is now losing irrigation water to its upstream riparian neighbors—Turkey, Syria,

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http://dx.doi.org/10.1016/j.rser.2014.05.073
1364-0321/

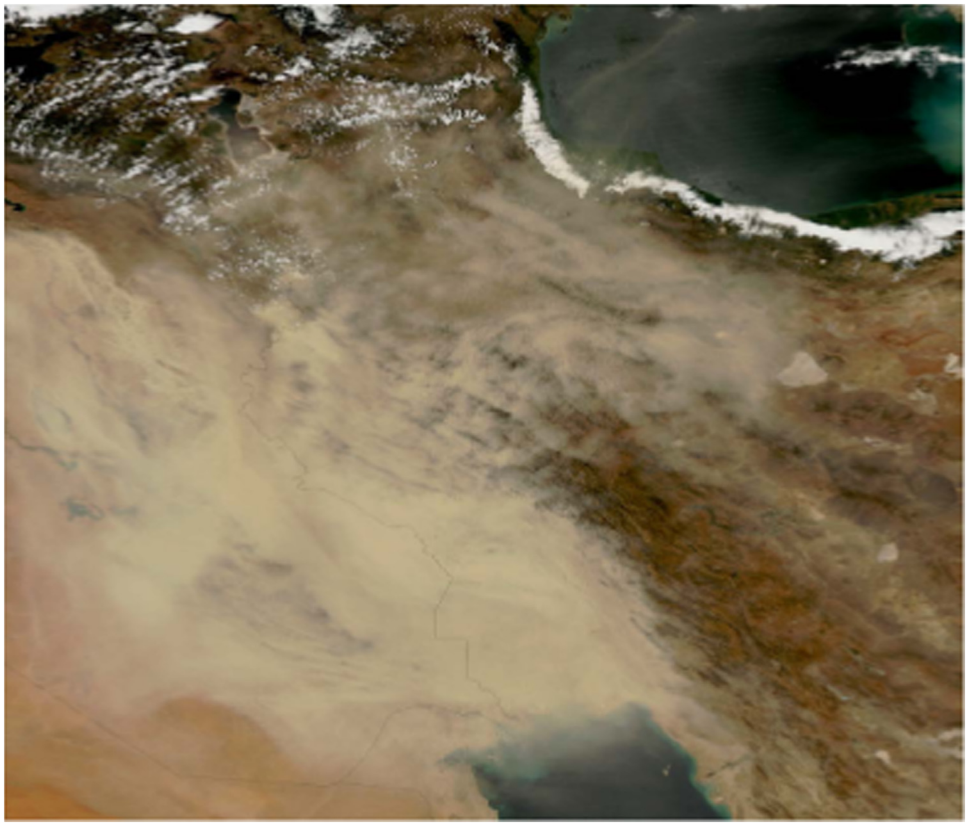

Fig. 1. Dust storms as observed from space images (5/7/2009).

and Iran. The reduced river flow-combined with the drying up of marshlands, the deterioration of irrigation infrastructure and the shrinking irrigated area is drying out Iraq. The Fertile Crescent, the cradle of civilization, may be turning into a dust bowl [2].

Dust storms are occurring with increasing frequency in Iraq. In July 2009 a dust storm raged for several days in what was described as the worst ever storm in Iraq's history (Fig. 1) as it traveled eastward into Iran, the authorities of this country closed government offices, private offices, schools and factories [2].

The output of PV is rated by manufacturers under Standard Test Conditions (STC), temperature = 25 °C; solar irradiance (intensity) = 1000 W/m^2, and solar spectrum as filtered by passing through 1.5 thickness of atmosphere. These conditions are easily recreated in a factory but the situation is different for outdoor. With the increasing use of PV systems it is vital to know what effect active meteorological parameters such as humidity, dust, temperature, wind speed, etc., have on its efficiency. The wide spreading usage of PV depends mainly on its applications at Iraqi atmospheric condition. Iraq is characterized by its high temperatures in summertime, in addition to its dusty environment. In Basra (south Iraq) high humidity weather is normal condition that must be taken into consideration when decision makers want to build a PV station.

The commercial PV panel efficiency is between 15% and 20% and dust accumulation on PV panel highly reduces its efficiency; its cleaning needs time and effort. This means higher maintenance costs with lower efficiency. This condition reduces PV market especially in countries with large oil and gas production and reserves like Iraq. Dust storms cause fractures in the PV panel that reduce live time. Humidity existence with dust accumulation on PV gives a magic mishmash of a hard layer cleaning resistance. Darwish et al. [3] clarifies that there are limited current research characterizing deposition of dust and their impact on PV system performance. As a result, the dust deposition is a complex phenomenon that must be dealt with its diverse site-specific environmental and weather conditions sources.

In spite of this pessimistic picture, Iraq lies in the high intensity region of solar energy [4,5]. Iraq is connected with Europe through Jordan, Syria and Turkey. In Iraq there are available areas suitable for the establishment of large power plants [6]. The huge reserve of natural gas available in Iraq will support the implementation of power generation for the short run in parallel with renewable energy projects [7]. Iraq has sufficient water for the requirement of cleaning the solar plant from dust and birds residues'. Huge amounts of electrical energy are needed at the time being in Iraq. This situation makes thinking in the production of electricity by solar energy and assisted with that generated by gas turbines stations at night a very brilliant and acceptable idea. This can be achieved whenever gas and solar energy are available in the same area as in Iraq [8,9].

This paper is a review of the Iraqi investigation of the effect of dust on PV performance. The study of the effects of dust on PV performance must take into considerations dust source, its constituents, pollutants particles that added to dust and finally its wipe away and how much of the performance can be recovered. In this paper dust sources, specifications and effect on PV performance in Iraq are reviewed. All the formerly mentioned points were subjected to intensive research but still many challenges are being faced by Iraqi researchers and many researchers are still not satisfied. This paper attempts to give comprehensive look on the most important Iraqi studies in this field defining the challenges that need more interest to improve PV performance in Iraqi environments.

2. The Iraq geography

One of the keys to the understanding of the importance and the complexity of Iraq and its role in current events lies in its location. Iraq, with a total area of 438,320 km^2, is bordered by Turkey to the

Fig. 2. Map of Iraq [9].

north, the Islamic Republic of Iran to the east, the Arabian Gulf to the southeast, Saudi Arabia and Kuwait to the south, and Jordan and the Syrian Arab Republic to the west [10]. Iraq lies in southwest Asia between latitudes 29° 5′ and 37° 22′ N and longitudes 38° 45′ and 48° 45′ E; it forms the eastern frontier of the Arab countries (Fig. 2). Its unique environmental, biological and social features, which are unlike anywhere else in the Arabian Peninsula, characterize this country. The estimated population in July 2011 is 30,399,572 persons with a growth rate of 2.399%. The capital city is Baghdad with a population of 5.751 million persons [11] (Fig. 3).

Iraq has four major geographic regions:

1- The Upper Tigris and Euphrates Upland: Southeast of it, the Al-Dibdibah is a gravelly plain with scrub vegetation that extends eastward into Kuwait and southward into Saudi Arabia. The Al-Jazirah Plateau is the cardinal feature in this region between the upper stretches of the Tigris and Euphrates. Although primarily flat, this arid region contains deep river valleys, the watershed of the two rivers, and some scattered highlands [12].
2- The Northeast Highlands: This region runs northwest to southeast, in the northernmost region of Iraq. Near and across the Iraqi border with Iran sit the Zagros Mountains, while to the north in Turkey are the Taurus Mountains. River basins between these ranges provide habitable areas. Moving southwest from the mountainous areas are hill regions that gradually become plains. The southwestern edge of the Northeast Highlands is marked by the Jabal Hamrin, a low-elevation ridge through which the Tigris River flows.
3- The Alluvial Plains: The central and southern parts of the Euphrates–Tigris drainage basin, are low-elevation plains subject to poor drainage and seasonal floods. Numerous marshlands and lakes are found there; the largest is Hawr Al-Hammar, south of the confluence of the Tigris and Euphrates. This marshy lake was drained following the 1991 Gulf War.
4- The Desert: 31% of Iraq's surface is desert. Years of inappropriate farming practices and mismanagement of water resources have exacerbated the effects of an already dry climate and contributed to increasing rates of desertification. Declining fertility, high soil salinity, erosion and the extension of sand dunes are pervasive problems [13]. On the southwest of the Euphrates lies a vast extension of the Syrian Desert that covers parts of Syria, Jordan, and Saudi Arabia beyond Iraq's borders. The deserts of southern Iraq are generally divided into the Al-Hijarah in the western area and Al-Dibdibah in the eastern sections. The Al-Hajarah Desert is rough, uneven limestone plateau cut by Wadis and depressions and strewn with loose flint and chart, flint-like quartz. The Al-Dibdibah is sandier and more gravelly than the Al-Hajarah [14].

The climate of Iraq must be characterized with some care. Iraq's mainly continental climate is characterized by being very hot and

Fig. 3. Relief of Iraq [6].

extremely dry in general, and frequently exposed to solar radiation. The climate can be described as mostly desert like with mild to cold winters and dry, hot, and cloudless summers. Yet, the potential for a variety of climatic or weather hazards such as drought, sandstorms and floods makes the reliance on short and long-term forecasts problematic [15] (Fig. 4).

Annual migrations of subtropical high pressure and mid-latitude low pressure are clearly reflected in Iraq's climate and three distinct climate regions are the result when classified using the Koppen climate classification scheme (Fig. 5) [16]:

a) The southern half of Iraq from the coastal areas near Basrah to the Syrian Desert is closest to the subtropical high pressure zone and consequently is classified as a Subtropical Desert.
b) The upland region north of Baghdad is significantly wetter, particularly in winter, and can be classified as a Subtropical Steppe.
c) Finally, in the northern mountain regions, where conditions are much cooler and rainfall more abundant, the climate is Mediterranean or Dry Summer Subtropical [17].

The arid landscape from the edges of the Syrian Desert in western Iraq to the coastal lowlands in the southeast is merciless. The presence of high pressure throughout the year has controlled this Subtropical Desert climate. This resulted in only small amounts of precipitation during the winter months when high pressure is occasionally displaced southward [18].

Temperatures are extremely hot in summer and mild in winter due to the variability of the incoming solar radiation (insulation) caused by the tilt of Earth's axis. The highest maxima in June, July, and August range between 43 °C and 50 °C. The monthly mean minima for January range between 1 °C in the south western desert and the north eastern foothills to 8 °C in the central part of the river plain. The lowest minimum is about −14.5 °C in the northern desert, −11 °C in the foothills and −8 °C in the central part of the river plain. Even at Basra near the coast the lowest minimum is −4.5 °C, showing the effect of cold waters [19]. In addition to the variability of insulation in Iraq, the location of the country astride the African and Asian landmass results in a continental influence indicated by broad annual as well as daily (diurnal) temperature ranges. This continently is primarily manifested through the rapid heating and cooling of the land surface due to its relatively low specific heat [20]. In other words, the land heats up quickly and cool down fast when compared to the oceans. Tables 1 and 2 presents the monthly rate of solar radiation at Baghdad, and the monthly rate of sun rising for the years (1983–2012). Table 3 presents the average monthly and yearly regular temperatures for Baghdad station for the period (1983–2012).

Wind and water are the cause of Iraq's most frequently occurring natural hazards: dust storms, sandstorms, and floods. Iraq experiences two types of wind patterns that trigger dust storms and sandstorms. From mid-June to mid-September, dry air masses from the Mediterranean are funneled between Saudi Arabia's high plateau and the mountain ranges in the north and

Fig. 4. Elevation and principal geographical regions of Iraq [9].

west of Iraq. The resultant northwesterly winds called "*shamals*" intensify as the summer progresses and the ground continues to heat [21]. From April to mid-June and again from mid-September to November, the wind pattern changes from southerly to southeasterly. Known as "*sharqis*", these currents produce winds that in general are gustier than but not as persistent as the summer "*shamals*". The resulting winds storms are sometimes interchangeably referred to as "*sandstorms*" or "*dust storms*" but technically the two are different. Because of its smaller size, dust can be lifted hundreds of meters into the air. In contrast, sand can be lifted only about 15 m. Thus, the wind storms that produce dramatic, towering walls of uplifted fine particles are dust storms [22,23].

The presence of poor dry soils combined with continuous winds during most of the year makes the potential for dust and sandstorms an important hazard to consider. Large area in Iraq, Syria and Jordan and North Africa has become a source of the dust storms affecting Iraq and often extends to neighboring countries. This is especially important in the southern deserts where vegetative cover is at a minimum and the supply of silt and sand is relatively abundant. However, even in more humid regions adjacent to the Tigris and Euphrates Rivers, this is becoming a problem due to poor irrigation practices leading to desertification [24]. While major dust storms make the news when they affect cities, the heavy damage is in the area of origin. These regions are affected by storms of dust and sand combined. Dust storms provide highly visible evidence of soil erosion and desertification. Once vegetation is removed either by overgrazing or over plowing, the wind begins to blow the small soil particles away. Because the particles are small, they can remain airborne over great distances. Once they are largely gone, leaving only larger particles, sand storms begin. These are local phenomena often resulting in dune formation and the abandonment of both farming and grazing. Sand storms are the final phase in the desertification process [25].

The importance of water for agriculture cannot be overemphasized in Iraq. Drought conditions affect not only the potential for rain-fed agriculture, but also alter the hydrologic conditions of the Tigris–Euphrates river system which is heavily relied on for irrigation. The occurrence of drought is related closely to two pressure systems: migrating low pressure systems from Europe and the strength of Siberian high pressure systems during the winter months [26]. Droughts occur as the result of decreased precipitation in the winter and spring which in turn is linked to the strength of Siberian high pressure. The stronger the Siberian high, the more likely westerly low-pressure systems will be blocked from reaching the interior of Iraq. In addition, warmer surface temperatures evaporate much of the available surface water, exacerbating conditions [27].

The country suffers severely due to land degradation and desertification problems, especially in its central and southern parts. Land degradation is one of the most serious ecological problems in the world. It entails two interrelated, complex systems: the natural ecosystem and the human social system. Causes of land degradation are not only biophysical, but also socioeconomic (marketing, income, human health, institutional support, and poverty), undermining food production and political stability [28].

Reference has already been made to the role of prolonged drought in exacerbating the severity and frequency of dust storms. This is due to several causes. The most obvious are the reduction of plant cover and the drying of the soil. Bare, dry soil is more

Fig. 5. Regional Köppen climate classification of Iraq [15].

Table 1
Monthly rate of the incoming solar radiation for Baghdad Station (J/cm^2/day) for the period (1983–2012) [14].

January	February	March	April	May	June	July	August	September	October	November	December	Average
333.1	348.2	469.1	541.4	726.8	732.4	731.6	661.2	560	435.4	289.1	245.1	106.1

Table 2
Monthly rate of solar radiance (theoretical and practical) at Baghdad Station (h/day) [14].

Month	Theoretical radiance (h)	Practical radiance (h)
January	10.15	6.4
February	11.1	7.5
March	11.55	8.1
April	13.2	8.8
May	13.59	10.2
June	14.3	13
July	14.1	12.8
August	13.29	12.2
September	12.22	10.7
October	11.19	9.1
November	10.18	7.5
December	9.59	6.1

susceptible to the actions of the wind. Plant cover reduces wind velocity at the soil surface and moisture improves cohesion between individual soil particles. However, the major effect of prolonged drought seems to be to force land-users to take greater risk and impose greater pressure on an already stressed environment [29].

3. Sand storms and dust in Iraq

Sand-dust storms, especially serious-strong sand or dust storms are hazardous weather with extreme calamity. When it occurs, sand-dust storms can move forward like an overwhelming tide and strong winds take along drifting sands to bury farmlands, denude steppe, attack human settlements, reduce the temperature, pollute the atmosphere, blow out top soil, hurt animals and destroy mining and communication facilities. These hazards bring about frost freeze to crops and result in a loss of production [30]. They accelerate the process of land desertification and cause serious environment pollution and huge destruction to ecology and living environment. The hazardous consequences severely threaten the safety of transportation and electricity supplies and contribute to unforeseen casualty to people's life and property.

When high winds at a threshold speed blow over areas with minimal vegetation cover, soils that lack snow and/or soil moisture

Table 3
Monthly and yearly rates for regular temperatures (°C) for Baghdad Station for the period (1983–2012) [14].

Data	January	Febraury	March	April	May	June	July	August	September	October	November	December	Total	Average
Average	10.8 10.56 Winter	12	16.2 22.66 Spring	23	28.8	34.8 34.8 Summer	35.3	34.3	30.1 23.7 Autumn	24.2	16.8	10.9	243.3	20.27

content [31], or soils that are vulnerable to surface disturbance a dust storm has the potential to occur [32]. Other types of areas that can also be vulnerable to dust storms when threshold winds are present are areas in which soils have dried out and displaced after a flash flooding event or areas with dried out lakebed sediments [33,34].

Desert soils are naturally resistant to wind erosion because they form a thin cohesive surface crust that helps to keep the soils intact. The crust is most prevalent in areas between plants because they help to stabilize and protect soil from wind and can trap suspended soil particles [35,36]. When the crust is disturbed or there is a reduction in vegetation cover, the risk of a dust storm occurrence is increased as the loosened sediments are free to be picked up by high winds [37,38].

Particle size plays an important part in both lifting and settling thresholds. Longer suspension times for smaller particles result in long periods of dust haze in arid areas. The more important relation is between particle size and wind velocity. The particles capable of traveling great distances usually have diameters less than 20 μm. These particles fall at a speed of about 100 mm/s, or roughly 4 in./s. Particles larger than 20 μm in diameter fall disproportionately faster: 50-μm particles fall at about 500 mm/s, or half a meter per second, while particles smaller than 20 μm are settled very slowly. 10-μm particles fall at only 30 mm/s. Smaller particles fall even more slowly: 2-μm particles fall at only 1 mm/s. The finest clay particles settle so slowly that they may be transported across oceans without settling. Relating these sizes to the real world, clay particles have diameters less than 2 μm, silt particles range from 2–50 μm, and sand-size particles are greater than 75 μm. As a result in clay and silt, appropriate source regions for dust storms have fine-grained soils. The threshold wind velocity (15 cm above ground surface) that can lift up and transport dust grains of (0.05–0.1 mm) in diameter is (3.5–4.0 m/s) [39,40].

Dispersion is primarily governed by turbulence, which mixes ambient air with the plume. Any increase in turbulence will increase the rate at which the plume disperses. The three kinds of turbulence that act to disperse a plume are mechanical turbulence, turbulence caused by shear, and turbulence caused by buoyancy. Mechanical turbulence is caused by air flowing over rough features such as hills and trees. Turbulence from shear can result from differences in speeds and/or direction. Buoyancy turbulence can be caused by something as dramatic as an explosion or as simple as bubbles of air rising during the diurnal heating of the surface. Particularly in the latter case, buoyancy is governed by the stability of the atmosphere [41].

Sand-dust storm is the generic term for sand and dust storms. It is a serious phenomenon of wind and sand which brings sand particles and dust silts into the sky and turns the air turbid (horizon visibility is less than 1 km). Sandstorm refers to the strong sand-carrying windstorm at force 8 (Beaufort scale) that blows up great quantities of sand particles from the surface into the air. Dust storm refers to the strong dust-carrying windstorm that blows up great quantities of dust and other fine grains into the atmosphere [42].

In general, two indicators, wind velocity and visibility, are adopted to classify the grade of intensity of sand-dust storms. For instance, authors in Ref. [43] classified the sand-dust storms into three grades. Namely, the feeble sand-dust storm develops when wind velocity is at force 6 (Beaufort) degrees and visibility varies between 500 and 1000 m. The secondary strong sand-dust storm will occur when wind velocity is at force 8 and visibility varies 200–500 m. Strong sand-dust storms will take place when wind velocity is at force 9 and visibility is less than 200 m. Ji-xi [44] defined the category of strong sand-dust storms into two grades, namely strong sand-dust storms and serious-strong sand-dust storms. When wind velocity is 50 m/s and visibility is <200 m, the sandstorm is called a strong sand-dust storm. When wind velocity is 25 m/s and visibility is 0–50 m, the sandstorm is termed a serious sand-dust storm (some regions name it Black windstorm or Black Devil).

In Iraq sand and dust storms occur mainly in spring season, which covers half of the total frequency of sandstorms (particularly the serious-strong sandstorm occurring in spring season). The summer and autumn seasons are the next in line. In terms of months in which sandstorms occur, April is the dangerous month with high frequency, March and May are lower and December and January.

During the recent decade, the frequency of sand-dust storms has increased year by year and the situation of overloading land resources cannot be improved in a short period of time. Along with global warming, constraints of shortage of water resources become as intense as ever. As consequence, sand-dust storms will bring about more harmful calamities to human beings.

Dust storms are considerable weather phenomena that describe a form of natural hazards in Iraq. Such phenomena have a wind speed of at least 40 km/h. It plays an active role in transporting and deposing materials of different sizes leading to change in the earth's surface [45,46].

4. The Iraqi dust specifications

US combat experienced a particular and critical issue in Iraq; the troop's individual combat weapons (M4 and M16 rifles) were jamming and failing to fire dependably. The problem was related to high levels of dust in the area combined with the properties of standard army cleaner, lubricant and preservative (CLP) [47]. An army study identified that dusts present in the world's deserts varies greatly in physical and chemical properties, variables that have significant implications for military operations [48]. US army conducted a study of soils and dust collected from areas of military activity in Iraq. The results concluded that the concentration of reactive chemicals, primarily salts and carbonates, is high in all Iraqi dust and soil samples and extremely high in many regions [49]. Although silica (quartz) is commonly the primary component, silica is usually less than 80% of the sample mass.

Several of the recorded elements were reactive chemical components that have the potential to corrode metal parts. A wide range of clay minerals occurs in the Iraqi samples. The three most common are muscovite, chlorite, and kaolinite. Most of the samples contain appreciable quantities of silt-sized (2–62 μm) and clay-sized (<2 μm) particles [50]. The clay-sized fraction includes minerals as well as other clay-sized components. Average

particle size of the sampled Iraqi dust is less than the average particle size of the dust used in current weapons testing procedures [51]. The average particle size of dust encountered in military operations in arid regions is much smaller than laboratory-generated quartz surrogate dust used in sand-and dust chamber testing of weapons [52]. The average particle size of dust taken from vehicles in Iraq was significantly smaller than the particle size of bulk soil samples. Further, the samples from vehicles had a higher concentration of reactive carbonates and sulfates. This reinforces that current chamber test methodology misrepresents real-world conditions [53].

Substantial amounts of soluble salt, carbonate, chlorides, and sulfates are present in nearly all the samples. Halite (sodium chloride), gypsum (calcium sulfate), and bassinette (calcium sulfate) minerals were also identified in the samples. The three primary components of the samples are silica (SiO_2), calcium, and magnesium ($CaO+MgO$) as well as the loss on ignition (LOI) fraction [24]. The remaining captions measured in the bulk dust samples include oxides of titanium (TiO_2), aluminum (Al_2O_3), iron (Fe_2O_3), sodium (Na_2O), potassium (K_2O), and phosphorus (P_2O_5). The varying concentrations of the potassium feldspar, plagioclase, and clay minerals in the samples increased with a greater abundance of silicate and clay minerals [54].

Water-soluble anions also occur in a wide range of concentrations. Sulfate (SO_4^{2-}) and chloride (Cl^-) concentrations determined by ion chromatography (IC) in both bulk samples and tactical vehicle samples occur in the greatest amounts relative to measured concentrations of nitrate ($NO_3{}^-$). The combined total concentrations of the three anions range from 672 ppm to 64,718 ppm [55]. Sulfate is present in nearly all the samples and exceeds 10,000 ppm ($\sim$1% sample weight), this is a significant concentration of sulfate due to the presence of the mineral bassinette ($CaSO_4 \cdot 0.5H_{20}$), a type of gypsum mineral. Some samples contained high concentrations of chloride, which indicates the presence of halite [56]. Meyers et al. [57] clarified that chlorides, sulfates, and dissolved calcium (from carbonates) under the right conditions can produce severe corrosion to metals commonly used in military installations.

Akhter and Madany [58] found that the dust in the urban area of both types street and house dust could form a source of pollution by heavy metals derived from three main sources; industrial, automobile activities, and weathered material, via the concentration of Pb, Zn, Cd, Ni and Cr in street and household dust, whereas in Baghdad, the authors of [59] claimed that the average concentrations of Pb, Zn, and Fe are 0.86, 0.105, and 10.88 $\mu g/m^3$ respectively. Al-Ali [60] showed that Mesopotamia deposits contributed Eolian deposits supplement.

Heavy metals are associated with various soil components in different ways and these associations determine their mobility and availability [61,62]. The distribution and concentration of most elements in soil shows a pattern related to geology, human influences and agricultural activity [63]. The essential trace elements include Co, Cr, Cu, Mn, Ni, Zn, and Se while Ag, As, Cd, Hg, Pb and Sb have no known essential function but causes toxicity above certain tolerance level. The most important heavy metals with regard to potential hazards and the occurrence in contaminated soils are As, Cd, Cr, Hg, Pb and Zn [64]. The concentration of these toxic elements in soils may be derived from various sources, including anthropogenic pollution, weathering of natural high background rocks, metal deposits [65] and may be waste dumping ground containing elevated concentration of heavy metals can be a continuous source of metal spreading to the surrounding [66].

Ahmed [67] indicated that the concentration of heavy metals shows important spatial variations than the seasonal variations. Regarding Pb and Cd, their percentages are stable during the four seasons of the year except in spring there was an increase in the Pb level as compared to the rest seasons, whereas the Fe scores are the highest concentration compared to the analyzed elements, possibly due to the dusty storms which has been believed to bring Fe from neighboring countries. Ni and Cu have the same level of concentration over all seasons. The sources of the studied heavy metals are believed to be the following: Cu is derived from chemical fertilizer and other agricultural activities, Pb, V, and Ni originated from the car exhausted waste. The occurrence of these heavy metals also suggests the possibility of negative health consequence of dust dispersal and deposition [68,69].

The high carbonate percentage of the dune sand of Najaf, Samawa, and Nasiriya suggest the proximity of these areas to the source rocks which is believed to be Euphrates, Fat'ha and Injana Formations, and Dibdibba Formation for Najaf dunes. Samawa dunes sand is from Fat'ha and Injana Formation besides, alluvial deposits. Nasiriya dune sand is from Dibdibba Formation and alluvial deposits [70,71].

The high concentration of Fe in dust particle proved that such particles are derived from rocks exposed in neighboring countries and Hussyiniate outcrops inside Iraq. The diversity in heavy minerals assemblages is attributed to the variation in the amount and stability of the transported heavy minerals and in the differences of wind direction [72].

Iraq experienced two devastating wars in 1991 and 2003 during which massive amounts of new weapons and sophisticated manufactured nuclear weapons were used. These were called Depleted Uranium (DU) [73]. Despite the passage of two decades of the first war and 10 years of the second war, their remains are still radioactive and residues are found in farm fields, along roads, near residential areas and even some of them within Baghdad, Basra, Nasiriyah, Maysan, Najaf, Karbala, Neynawa, Babel cities and other Iraqi provinces [74] (Fig. 6) .

In addition, radioactive dust resulting from the munitions explosion was transmitted by the wind to all parts of Iraq and also to the neighboring countries [75]. The DU aerosol is deposited on soil surface, transported far from the vicinity of the target, or re-suspended in the air by the wind action [76]. Burning of tanks and armored vehicles led to the formation of large quantities of fine aerosol containing predominantly poorly soluble uranium oxides [77]. The DU aerosol is deposited on soil surface, transported far from the vicinity of the target, or re-suspended in the air by the wind action [78].

A soil's affinity for uranium is characterized by its uranium 'sorption' (a term that refers to processes occurring at the solid-solution interface), which ultimately affects the extent of potential plant uptake and groundwater contamination. It is known that the pH of soil affects its uranium sorption: Uranium is more mobile in alkaline soils than in acidic soils due to the formation of stable oxy-anions with oxygen and carbon [79]. Soils that are high in organic matter are observed to possess a higher affinity for uranium, thus causing less uranium to be released into the groundwater and plant roots. Semi-arid soils have less affinity for uranium than moist soils, increasing uranium mobility from the surface to deeper soil. Uranium showed slow migration and the soils contaminated with Depleted Uranium are difficult to remediate, and thus pose a long-term potential risk to the environment and humans [80,81].

Shahsavania et al. [82] measured PM_{10}, $PM_{2.5}$, and PM_1 concentrations from April through September 2010. Overall mean values of 319.6, 407.07, 69.5, 83.2, 37.02 and 34.9 mg/m^3 were obtained for PM_{10}, $PM_{2.5}$, and PM_1, respectively, with corresponding maximum values of 5337.6, 910.9, and 495 mg/m^3. These results are similar to those found by other studies. For example, PM_{10} concentrations higher than 3000 mg/m^3 and produced by dust events were observed in a study conducted in Iraq, Kuwait, and Saudi Arabia [82]. The main component of these events was the coarse fraction of the particles. The high $PM_1/PM_{2.5}$ ratios

Fig. 6. DU polluted sites in Iraq [67].

showed that PM_1 constitutes the main fraction of the total mass of $PM_{2.5}$ [83,84].

5. The Iraq electricity conditions

Iraq is already the world's third-largest oil exporter and has the resources and plans to increase rapidly its oil and natural gas production as it recovers from three decades punctuated by conflict and instability. Success in developing Iraq's fossil fuels potential and effective management of the resulting revenues can fuel Iraq's social and economic development. Failure will hinder Iraq's recovery and put global energy markets, of course, for trouble [85,13].

Rising incomes have led to an increase in consumption of electricity for household appliances and of fuel for the rapidly growing vehicle fleet and for industry. Catching up and keeping pace with rising demand for electricity is critical to Iraq's national development [86]. A key obstacle to Iraq's development is the lack of reliable electricity supply. Power stations produce more electricity than ever before, but supply is still insufficient to meet demand; power cuts are a daily occurrence and the use of back-up diesel generators is widespread. Building a modern electricity system, with sufficient generation capacity and supplies of fuel, is recognized as an immediate priority. Iraq needs 70% more net power generation capacity to meet demand fully. With the exception of hydropower, deployment of renewable sources of energy is projected to remain below Iraq's potential [87].

Despite a significant increase in grid-based electricity capacity in recent years (peak net daily production in 2011 was around 70% higher than 2006), it is still far from being sufficient to meet demand. The net capacity available at peak in 2011 was around 8 GW while the estimated net capacity required to meet peak demand was 15 GW, resulting in a need for around 7 GW more available capacity (an increase of around 70%). This is before taking account of the increase in demand which is likely to occur as the electricity supply becomes more reliable. Building additional generation capacity and ensuring that it has adequate supplies of fuel is the immediate priority for the power sector in Iraq.

To try and fill some of the electricity supply gap, around 90% of Iraqi households supplement the public network with private generators, either a private household generator or a shared generator operating at neighborhood level [88]. The generation provided from such sources is difficult to quantify, but it may be estimated that in 2011 shared generators accounted for 3 TWh on top of the 37 TWh of consumption that came from the grid. In central Baghdad alone, a 2009 survey estimated that approximately 900 MW of private generation was available for use [89]. Private generators currently play an important role in reducing Iraq's shortfall in electricity supply (helping to reduce the number of blackouts) and also to bring benefits in terms of flexibility and providing electricity access to rural areas. However, even though private generators receive subsidized fuel from the government, the price of the electricity they provide to consumers is considerably higher than grid electricity. Residential customers are paying 10 to 15 times more for the electricity supplied from private generation than from the grid. As well as being an expensive way to provide electricity, diesel generators also contribute to local air pollution [90]. Even with the use of non-grid generation, the average availability of electricity to end-users (from all sources) was limited in 2011 to around 11–19 h per day varying across the country.

An additional challenge for Iraq is that electricity demand is seasonal, with the highest peak occurring in the summer months as a result of very high temperatures in most of the country. During the summer, peak hourly electricity demand could be expected to reach

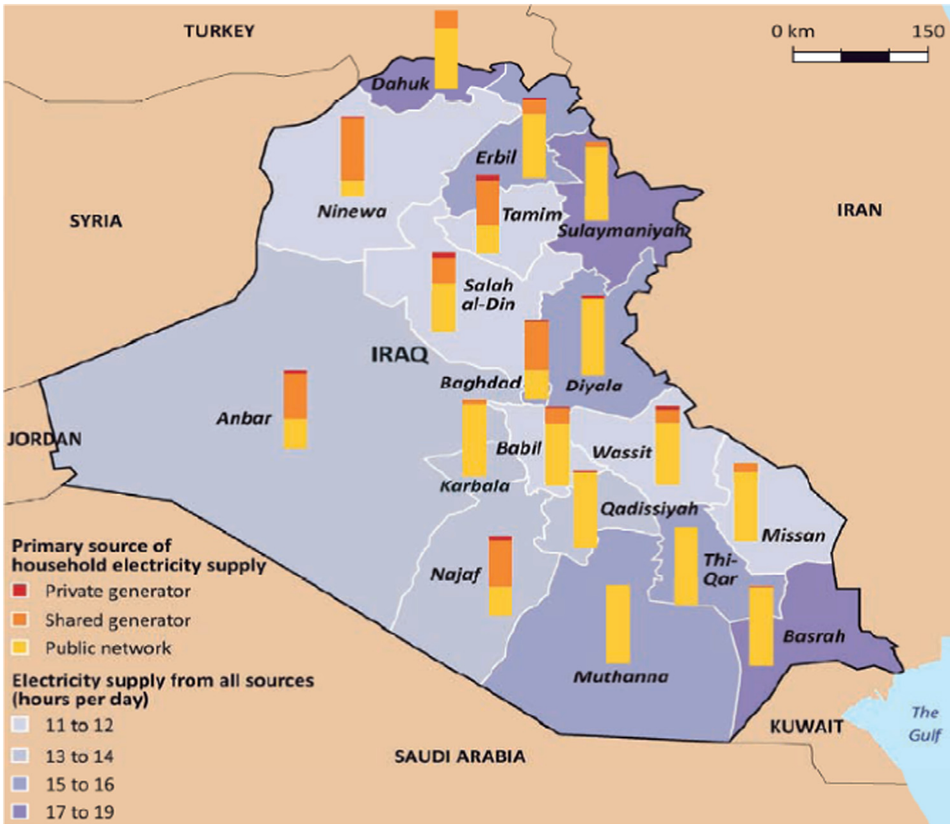

Fig. 7. Iraq source and reliability of electricity supply by governorate 2011 [81].

levels around 50% above the average demand level increasing the gap between grid-based electricity supply (operating at capacity) and demand [91] (Fig. 7).

Existing generation, distribution and transmission infrastructure are in need of rehabilitation and upgrading as well as rapid expansion to catch up with and meet growing demand for electricity. Just over half of Iraq's existing nominal generation capacity pre-dates to 1990; a further 47% has been added since 2000; a mere 2% (250 MW) was added during the entire 1990s during which the state of the existing generation stock also deteriorated significantly. Recent capacity additions have helped to improve the overall efficiency of the sector, but it is still low by international standards and conversion losses which represent a significant item in Iraq's energy balance. The efficiency of gas-fired plants in particular is currently 31% (compared with around 55% achievable for new combined cycle gas turbines under good operating conditions) [92].

Meeting demand for electricity with reliable and continuous supply is the main immediate concern for Iraq's electricity sector. Iraq has very good solar resources. Even though the Middle East's best solar irradiance is farther south – in Saudi Arabia and Yemen for example – Iraq's average solar irradiance is similar to that in North Africa. Iraq also has some history of research into solar power (which was curtailed significantly during the decades of wars and sanctions). Today, solar research activities are sponsored by the Ministry of Electricity and the Ministry of Science and Technology. The Ministry of Electricity has a number of off-grid solar research stations, with a capacity of a few tens of megawatts (MW). Despite the strength of the resource, grid-connected solar electricity generation – either through photovoltaic (PV) or concentrating solar power (CSP) – will remain a high-cost option, compared to fossil fuels [93].

There are a number of research projects being implemented such as the measurement data of solar radiation at the Iraqi Universities, the project to supply communication stations in remote areas using solar energy, the programs for the manufacture of solar cells and PV systems in the implementation of the state universities, and a feasibility study for the application of PV systems for pumping water from wells for the cultivation of the remote areas.

6. The Iraqi scientific activities on the effect of dust on PV systems

The biggest problem facing the world during recent years in the field of the solar energy is the settling of atmospheric dust onto the surface of the solar panels. This atmospheric dust has several effects on the use of PV power systems including the decrease of the amount of sunlight reaching the surface and the accumulation of dust on solar panel surface which reduces the transmission of solar radiation that reaches the solar cells. This leads to the decrease of the performance efficiency [94]. The effect of dust on PV performance has been investigated in different ways. Sayigh [95] reported a power decrease of about 11.5% in a PV module exposed for only 72 h in Riyadh, Saudi Arabia. The effect of sand dust layer on beam light transmittance at a PV module glazing surface have been investigated by AL-Hasan experimentally and mathematically [96]. Kaldellis and Kokala [97] evaluated experimentally the actual performance of five identical pairs of roof-top PV-panels, operating in the aggravated urban environment of Athens (from the atmospheric air pollution point of view). Then they experimentally investigated and modeled the effect of three types of dust (red soil, limestones and ash) [98]. The impact of dust accumulation, humidity level and the air velocity has been elaborated separately and finally the impact of each on the other was clarified by Mekhilefa et al. [99]. Moreover, sand and dust particle accumulation on PV modules in dry regions has been numerically modeled and analyzed by Beattie et al. [100]. Mani

and Pillai [101] has reviewed the current status of research in studying the impact of dust on PV and has identified challenges and recommended further pertinent research.

Iraqi investigated the effect of dust storms on overall solar radiation rates of Baghdad city. The study concluded that the dust storms that happened on 2012 in Iraq had a greater influence on the total solar radiant that was recorded and gathered at Baghdad City for one year measurement. Moderate and high intensity dust storms were repeated and some of them were extended for many days. These storms caused reduction in the solar radiation from their natural rates [102].

Al-Rasoul et al. [103] collected samples from three areas in Baghdad during dust storm occurred on 18th of June 2009 to characterize elemental particle size and composition by different techniques. Tests detected six minerals which are calcite and quartz presented as a major components, dolomite, kaolinite, gypsum and plagioclase present as miner components. Some traces of lead, nickel, and chromium were found in the samples. The analysis of particle size has revealed that the majority particle distribution was between 32 and 45 μm.

The soluble salts of the dust could affect the PH of natural water, underground water, or the soil PH [97]. Recently the airborne carbonate (CO_3^{2+}) in suspended dust as an atmospheric buffer can affect atmospheric chemistry and aerosol characteristics because its alkalinity favors the uptake of SO_2 and NO_x and their conversion to SO_4^{2-} and $NO_3{}^-$ on the surface as well as removal of HNO_3 and H_2SO_4 from the gas phase [104,105].

Beattie et al. [100] examined electricity generation of hybrid PV/wind systems in Iraq. They proposed a hybrid system with renewable resource of power generation for grid connected applications in three cities in Iraq. Results showed that it is possible for Iraq to use the solar and wind energy to generate enough power for some villages in the desert or rural area.

Kasim et al. [106] focused in his study on achieving energy efficiency through utilizing solar energy and conserving energy. This task can be accomplished by the implementation of the major elements related to energy efficiency in housing design such as embarking on an optimum PV system orientation to maximize solar energy and produce solar electricity. All the precautions were taken to minimize the consumption of solar energy for providing the suitable air-condition to the inhibitor of the solar house in addition to use of energy efficient appliances and the consideration of the practices of the individuals and communities toward transferring useful and appropriate technologies for providing the required solar electric energy. The study clarified the obstacles which restricted wide-scale implantation of these medium power PV systems. One of these major obstacle is the need of relatively big size battery storage units necessary for continuing supply of electricity demand, especially during the absence of solar radiation. This obstacle could be overcome by the adaptation of a backup generator theme through a connection of the PV system station to the conventional source of energy which acts as an energy storage source for the PV array assembly. Accordingly, the PV array size, as well as the cost, could be minimized effectively by installing a suitable diesel generator to support the PV system during the peak load periods [107].

PV systems are especially well suited to locations where accessing a tradition sources of energy is either not feasible or expensive. In many such locations, PV technology is the least-cost option to meet energy needs for the operation of electric appliances to run the normal activities for the settlement in these remote places. Therefore, it is feasible to use this technology to provide the energy for running a social welfare centre located at these far distance places since it is easy to extend the size of the PV system to include supply electric energy to other essential equipments such as a delivery of decent amounts of underground water that are necessary to the inhibitors of the centre. Diesel generators that are usually used to electrify the social centers and located at different places away from the utility grid are not the right solutions both economically and environmentally. Three alternatives have been studied, evaluated and represented by diesel generators, stand-alone PV system and hybrid PV system. It was found that the hybrid PV system is the most economical among the three. However, from environmental point of view the stand-alone PV system will be the more suitable bearing in mind that the stand-alone PV system can afford for additional load demands during off-peak load demand periods [108].

Kubba [109] presented a method to measure the effect of cell mismatch on IV and PV modules. An accurate measurement of the effect of cell mismatch may help module manufacturers select their cell sorting strategies and binning tolerances. In this study, the parallel configuration produced marginally more power even when absent of mismatch conditions, but produced significantly more power as mismatch arises on the array.

Al-Najjar [110] investigated the effect of one-axis daily tracking and fixed system to evaluate the PV performance for Baghdad. The experimental measurements included incident solar radiation, load voltage and load current. The experiments were carried out during six months including wintertime to simulate the one-axis daily tracking. The azimuth angle was due south while the tilt angle was being set to optimum according to each day of simulation. The second set of experiments was done to simulate the PV module at fixed angles. The study found that there is a significant power gain of 29.6% for the tracking system in respect to the fixed one. The one-axis daily tracking was much more effective near winter solstice as compared to other months.

Al-Douri et al. [111] studied three alternatives represented by diesel generators, stand-alone PV system and hybrid PV system. The study found that the hybrid PV system is the most economical among the three and the stand-alone PV system is the most suitable from an environmental point of view. The outcomes of this study is that the real implementations of solar energy system will provide the electrical power to run any application in rural areas such as villages located in remote areas.

Theoretical studies of photovoltaic and modeling techniques using equivalent electric circuits were conducted by Kubba and Samair [112]. The use of equivalent circuits makes it possible to investigate the characteristics of a PV cell. The study results show that the PV model using the equivalent circuit in moderate complexity provides good match with the real PV module. This model can be generalized to any PV panel which it is enough to calculate the panel parameters (RS and Is) and PSPICE model of diode only.

Kubba and Samair [113] attempted to design and simulate two input converters. The first input is a photovoltaic module and the other is a battery. Two input dc–dc buck converter has been proposed to combine several clean energy sources. The results clarified that this converter was simulated to improve the validity of the PV panel model. This is achieved by comparing the results of the converter with a dc battery to that with the PV panel model. The converter with two sources gave comparable results with a good agreement between them. The PV model can be used for training personnel in the basic operation of solar energy systems.

Many valuable studies were conducted in the Iraqi neighborhood countries examining the effect of dust on PV arrays. Nimmo and Saed [114] found a 40% reduction in PV panels' efficiency in a period of six months of the Saudi Arabian weather. Sayigh [115] indicated a reduction of 30% in flat plate collector after 3 working days without cleaning. Said [116] reported a reduction of 7% in PV panel performance in Saudi Arabia region. In Alamoud's [117] study, efficiency decrements from 5.73% to 19.8% were recorded. The variation depended on the type of module exposed to Saudi

environment. In Kuwait Hasan and Sayigh [118] examined the reduction in transmittance due to tilt angle variation of glass plates. The study was conducted during 38 continuous days in the Kuwaiti desert. The results showed a reduction of 64%, 48%, 38%, 30% and 17% for tilt angles of 0°, 15°, 30°, 45° and 60°. Wakim [119] adduced a 17% reduction in PV modules efficiency after 6 days without cleaning.

7. The Iraqi research efforts on cleaning PV panels

The authors in Ref. [120] introduced an adequate and comprehensive survey for worldwide studies about cleaning PV panels; one can refer to it to follow the recent modernization in this issue. Iraq has a dusty climate and surrounded by deserts belt. The accumulation of dust on the solar panels will lead to reductions in the panels' transmittance [121]. For long-term operation of PV arrays, it will be necessary to develop techniques to remove the deposited dust on the solar panel surface. The following removal methods are studied and examined in Iraq [122]:

1) the natural method (wind lift, wind induced vibration);
2) the electromechanical method (shaking by sound our mechanical actuators);
3) the mechanical method (cleaning tools, cleaning robot systems);
4) the electrical method (electrostatic and electrodynamics); and
5) the physical-chemical method (self-cleaning materials).

For the natural dust removal, the only significant category for these methods is rainfall and wind clearing and then these are made possible by simply choosing an array orientation other than a horizontal one [88]. The other method of dust removal is the electrostatic type. If the PV array surface is charged, the array will attract particles of opposite charge and repel particles of the same charge [123].

Sims et al. [124] studied the problem of the accumulation of dust on the solar panels surface which causes the decrease of its performance sharply. The authors invented a new technique to reduce the accumulated dust on the solar panel surface and compared it with the fixed solar panels which were installed at tilt angles 30° and 45°. The new technique using movable platform was attached to two-axis solar tracking system with PV panels to reduce the amount of daily accumulated dust on solar panel, which comes from the effect of gravitational forces on dust particles. During the daily working mechanism of the tracking system and at the sunsets, the direction of the solar panel is changed from west to east for the horizontal axis (Azimuth) with the change of tilt angle of the PV panel to become more than 90° (about 95°) for the vertical axis (Altitude). This process is repeated daily at sunset to take the advantage of this movement. Vibration will also help to displace the deposited dust particles on PV panel surface. The change in tilt angle will make the center of mass of the dust particles outside the PV panel any discarded entirely from the influence of gravitational force. The results indicated that the maximum losses of the output power due to accumulation of dust on the fixed PV panels are about 31.4% and 23.1% respectively for 34 days period of accumulation, while the maximum losses of output power for the PV panel with two-axis tracking system are about 8.5% for the same period of accumulation [124].

Dihrab and Sopian [125] studied the effect of the natural deposition of dust in Baghdad on PV panels. The accumulated dust thickness increases with time. Hence, the increase of the tilt angle of the PV panel leads to the reduction of the losses due to the decrease of accumulated dust. The dust accumulation on the surface of PV panel causes decrease in the performance about (35–65) % for one month accumulated time. The effect of height on the accumulation of dust is less than the effect of tilt angle Table 4 [122]. When the average wind speed increased in some months, some reduction of the accumulated dust from the surfaces of solar modules occurred. June and July at Baghdad city have high average wind speed which is 6.19 m/s and 6.04 m/s, respectively [122]. In the dry weather the adhesive force between the dust atoms and the glass cover of PV panel are the only reason for dust deposition. There are many dust layers raised on the PV panel surface in weather with high humidity [126]. The study shows that the rain in some months causes natural cleaning for PV panels, especially at February and March. The increase in ambient temperature causes small increase in short circuit current but large decrease in open circuit voltage and also large decrease in the maximum output power [76].

Astaw [127] clarifies that the best way to eliminate the effect of the accumulated dust on the solar panels is to clean the panels. But cleaning the solar panels is also a problem from an economic side view. The normal way to clean the solar panels is washing them and this method needs time in addition to the spending of money given to a cleaning agency. Practically, the cleaning process must be done frequently increasing the spending money for cleaning. Sabah and Faraj [128] exploited a new approach of self cleaning (a solar panel supported by auto-cleaning robot). A two linked-track vehicle supplied by brushes which was proposed by Zhang et al. [129] was used. The robot's structure was designed to fit the specification of the flat panel's surface. The robot's brushes are driven by DC-motors the movement of which was controlled by a microcontroller. The DC-motors produced a rotational motion that was converted to a linear motion by means of a belt where the brushes will be fixed on the belt. The sufficient electrical power which is needed to drive the DC-motors will be supplied from the solar panel itself. This method has many advantages and one of which is that there will be no money to be paid for a cleaning agency. More time will be saved by reducing the periods of time that must be spent to clean those panels. In addition, frequent cleaning will ensure good transmittance for the array. Since robots are capable of working in hazardous environments, more dangerous operations are being handled by robots. Thus, the workers' exposure to hazard conditions will be eliminated. Fig. 8 shows the low cost wheeled mobile robot for cleaning. There is a new technique using super hydrophobic nano-self cleaner for dust removal from PV modules surfaces. This material is used as a coating self-cleaning glass that stops dust and bird residues from sticking to PV panels. This coating material approved that it keeps PV panels clean, maintains its efficiency, and ensures the electricity produced is at the maximum amount. The hydrophobic

Table 4
Monthly and yearly rates for wind speed for Baghdad Station for the period (1983–2012) [14].

Data	January	Febraury	March	April	May	June	July	August	September	October	November	December	Average
Average	2.55	2.87	2.91	2.97	3.25	3.88	4.01	3.45	2.76	2.6	2.48	2.38	3.01
	2.6		3.04			3.78			2.6				
	Winter		Spring			Summer			Autumn				

Fig. 8. Low cost wheeled mobile robot for cleaning [104].

material properties repel water more quickly than uncoated "self-cleaning glass" as studies found on typical PV panels. Treating cell with this coating material is more efficient during inclement weather [130]. Unfortunately, due to early stage national market and the present difficulties any data about using this method in Iraq is not available.

8. A critical evaluation on research conducted on dust effect on PV in Iraq

Iraqi researchers investigated the effects of dust on the PV performance characterized by studying parameters that influence the deposition of dust. Researchers have succeeded in defining dust causes and its origin and type of its elements and the relation of all that with the PV performance. There are still some parameters that need to be overcome to achieve better utilization for the PV system which leads to higher dependence on solar energy and higher reduction of fossil fuels dependence. These challenging fields of research are as follows:

- Most studies into experimental investigation of dust accumulation did not indicate the properties (optical, size, geometry, and electrostatic deposition behavior) of natural dust. These properties need be characterized. The biological and electrochemical properties of dust need to be investigated for various Iraqi locations.
- All the revised investigations were done on limited PV array areas'. There is no large scale PV station in Iraq to be tested.
- There is a dereliction in studies based on mathematical models that connect dust particle geometry, constituents in addition to pollutants accumulated on the particle on the PV performance and cleaning.
- The Iraqi studies did not demonstrate a concern on electrostatic attraction behavior of the PV panel on dust accumulation and cleaning.
- Cleaning the PV arrays with water contains scaling and its effects on dimensioning the PV performance need more investigations and measures.
- Bird dropping and their subsequent cleaning effects on the PV performance must be considered where large part of Iraq's area is agricultural and birds' numbers augment in these areas.
- The definition of the typical PV cleaning procedure must be used to recover the PV panels' efficiency loss because dust is still not defined.

9. Conclusions and recommendations

Iraq suffered from nearly a decade of war and two decades of drought. A new dust bowl appears to be forming. The country suffers severely due to land degradation and desertification problems, especially in its central and southern parts. Several elements in Iraqi soils and sand were recorded as reactive chemical components which have the potential to corrode metal parts. The Iraqi dust in urban area could form a source of pollution by heavy metals derived from three main sources: industrial, automobile activities, and weathered material, via the concentration of Pb, Zn, Cd, Ni and Cr in street and household dust. Depleted Uranium was used in 1991 and 2003 wars by the US troops. The DU aerosol is deposited on soil surface, transported far from the vicinity of the target, or re-suspended in the air by wind action.

Iraq is already the world's third-largest oil exporter and has the resources and plans to increase rapidly its oil and natural gas production. Meeting with the rising demand for electricity is critical to Iraq's national development where the main obstacle to Iraq's development is the lack of reliable electricity supply. Iraq's electricity demand is seasonal, with the highest peak occurring in the summer months as a result of very high temperatures in much of the country. Iraq has very good solar resources. Iraq's average solar irradiance is similar to that in North Africa. Iraq also has some history of research into solar power. Today, solar research activities are sponsored by the Ministry of Electricity and the Ministry of Science and Technology. The Ministry of Electricity has a number of off-grid solar research stations, with a capacity of a few tens of megawatts (MW).

This paper reviewed the current state of Iraqi research works into the impact of dust deposition on the performance of solar PV systems and also identified the challenges to further research in this area. The estimation of the status of research has been discussed. The study's main conclusions on the effect of dust on PV performance can be summarized as follows:

1. Iraq can solve the local problem of lack of electricity and could be the second source of energy after the European countries because of the available broad lands, solar energy, wind energy, geothermal energy and gas reserves.
2. The Iraqi researchers perceive the high effect of dust storms on PV performance. Studies were conducted to define exact causes for dust storms and methods for treating.
3. The Iraqi studies of the effect of dust storms on overall solar radiation rates of Iraq were conducted. It is concluded that the dust storms that happened during the last years in Iraq have had a great influence on the total solar radiation that were recorded and gathered at Baghdad city for one year measurement. These storms caused high reduction in the solar radiation from its natural rates.
4. Many new Iraqi studies that were concerned with the effect of dust on the PV performance and utilization were reviewed. Clay minerals occur in the Iraqi soil and sand samples. The three most common are muscovite, chlorite, and kaolinite. Most of the samples contain appreciable quantities of silt-sized (2–62 μm) and clay-sized (<2 μm) particles.
5. The Iraqi dust in urban area could form a source of pollution by heavy metals derived from three main sources: industrial, automobile activities, and weathered material, via the concentration of Pb, Zn, Cd, Ni and Cr in street and household dust.
6. Iraq has a very good potential for solar energy harnessing because of the long daily duration of sunshine hours and high levels of solar radiation. Iraq's average solar irradiance is similar to that in North Africa.
7. Meeting with the rising demand for electricity is critical to Iraq's national development where the main obstacle to Iraq's development is the lack of reliable electricity supply. Iraq's electricity demand is seasonal, with the highest peak occurring in the summer months as a result of very high temperatures in most regions of the country.
8. A recent study remarked that the success in utilizing PV systems in Iraq depends mainly on preventing these arrays and cleaning them from dust. Many studies presented the Iraqi efforts on cleaning the PV arrays and the improvement of its performance. More investigations need to be conducted on the effective methods of the PV cleaning.
9. It is recommended that a solar plant rather than street lighting should be installed. The advantages of having solar farm area are: easy monitoring and maintenance, and sharing common facilities, hence saving the construction cost and easy identification of faulty solar streetlight as each solar farm will be equipped with a monitoring system and less effect of dust on PV.

References

[1] UN Public Information Office (UNPIO), 2013. 〈http://www.iq.one.un.org〉. [accessed on May 2013].
[2] Brown LR. World on the Edge: How to Prevent Environmental and Economic Collapse. Earth Policy Institute, 2011, 〈http://www.earth-policy.org〉.
[3] Darwish ZA, Kazem HA, Sopian K, Alghoul MA, Chaichan MT. Impact of some environmental variables with dust on solar photovoltaic (PV) performance: review and research status. Int J Energy Environ 2013;7(4):152–9.
[4] Mohamed FM, Jassim AS, Mahmood YH, Ahmed MAK. Design and study of portable solar dish concentrator. Int J Recent Res Rev 2012;3:52–9.
[5] Hussein BN, Dhia IAE, Hussein J. Introducing a PV design program compatible with Iraq conditions. Energy Procedia 2013;36:852–61.
[6] Chaichan MT, Kazem HA. Thermal storage comparison for variable basement kinds of a solar chimney prototype in Baghdad – Iraq weathers. Int J Appl Sci 2011;2(2):12–20.
[7] Alasady AMA, Solar energy the suitable energy alternative for Iraq beyond oil. In: Proceedings of the international conference on petroleum and sustainable development (IPCBEE), Singapore, vol. 26, 2011.
[8] Sharif Salah FA. The project: Iraqi DESERTEC is the future second electricity supplier to Europe through Turkey. Int J Sci Eng Res 2012;3(11):1–8.
[9] Lahmeyer International (GmbH), Bad Vilbel, Integrated Solar Thermal Power Plants in the Al Anbar Region of Iraq, Terms of Reference for Consulting Services for Preparing a Pre-Feasibility Study, Germany, Oct 2011.
[10] Federal Research Division (FRD), Library of Congress, "Country Profile: Iraq," August 2006. 〈http://www.lcweb2.loc.gov〉. [accessed on May 2013].
[11] Omer TMA, Eroding soils and expanding deserts, Country Pasture/Forage Resource Profile, FAO, 2011.
[12] Encyclopaedia Britannica Online, "Tigris-Euphrates River System: Physical Features," 2009. 〈http://www.britannica.com〉.
[13] Kazem Hussein A, Chaichan Miqdam T. Status and future prospects of renewable energy in Iraq. Renew Sustain Energy Rev 2012;16(8):6007–12.
[14] Colbert C. Middle east patterns: places, peoples, and politics, boulder. Colorado: Westview Press; 2000.
[15] Mohammed AA, Dust storms monitoring, prediction and allocation of sources, Scientific and Technical Subcommittee on the Peaceful Uses of Outer Space, Fiftieth Session, Vienna International Center, Vienna, Austria, 2013.
[16] King WC, Eugene J, West Point PNY, Anderson PG, Cowher DD, Dalton JB, et al. In: Malinowski Jon C, editor. Iraq: a geography. Department of Geography & Environmental Engineering United States Military Academy; 2003.
[17] Muir J., Iraq Marshes Face Grave New Threat, BBC News, 24 February 2009. 〈http://www.news.bbc.co.uk〉. [accessed on May 2013].
[18] UN Data. "Country Profile: Iraq." No date. 〈http://www.data.un.org〉. [accessed on May 2013].
[19] Bureau of Consular Affairs (BCA), U.S. Department of State, Iraq: Country Specific Information, 30 August 2010. 〈http://www.travel.state.gov〉. [accessed on May 2013].
[20] McKnight TL, Hess D. Physical geography: a landscape appreciation. 7th ed.. Upper Saddle River, NJ: Prentice Hall; 2002.
[21] Iraqi Meteorological Organization (IMO), Unpress date for the period (1983-2012), Baghdad, 2013.
[22] Thompson Wiley. Country map, "location,". In: Malinowski Jon, editor. A regional geography. West Point, NY: U.S. Military Academy Press; 2002. p. 2002.
[23] Library of Congress, 1988. "Iraq—A country study". 〈http://www.loc.gov〉. [accessed on May 2013].
[24] Crook J, Climate analysis and long range forecasting of dust storms in Iraq [M.Sc. thesis], applied to Naval Postgraduate School in June 2009.
[25] Public Information Office (UNPIO), UN envoy supports greenbelts in Iraq to combat sandstorms, Baghdad, February 23, 2013.
[26] US Ministry of Water Resources (USMWR), Iraq Reconstruction–Water Resources Sector, Speech by the Minister of Water Resources in USA, 2005.
[27] Fadhil AM. Land degradation detection using Geo-information technology for some sites in Iraq. J Al-Nahrain Univ 2009;12(3):94–108.
[28] Pease P, Vatche P, Tchakerian N, Tindale N. Aerosols over the Arabian Sea: geochemistry and source areas for aeolian desert dust. J Arid Environ 1998;39:477–96.
[29] Yaalon D. Comments on the source, transportation and deposition of Saharan dust to Southern Europe. J Arid Environ 1996;36:193–6.
[30] Ackerman SA, Chung H. Radiative effects of airborne dust on regional energy budgets at the top of the atmosphere. J Appl Meteor 1992:223–33.
[31] A. Al-Dousari and J. Al-Awadhi, Dust fallout characteristics within global dust storms major trajectories, Arab J Geosci in press, http://dx.doi.org/10.1007/s1257-012-0644-0.
[32] Dagvadorj D, Natsagdorj L, Dorjpurev J, Namkhainyam B, Gomboluudev P, Batimaa P, et al. Climate change observation and research in Mongolia. Ulaanbaatar, Mongolia: Ministry of Environment, Nature and Tourism; 32–57 (Mongolia assessment report on climate change).

[33] de Longueville F, Ozer P, Doumbia S, Henry S. Desert dust impacts on human health: an alarming worldwide reality and a need for studies in West Africa. Int J Biometeorol 2013;57(1):1–19.
[34] Gautam R, Hsu NC, Lau KM. Premonsoon aerosol characterization and radiative effects over the Indo-Gangetic plains: implications for regional climate warming. J Geophys Res 2010;115:D17208.
[35] Goudie AS. Dust storms: recent developments. J Environ Manag 2009;90: 89–94.
[36] Kimura R. Effect of the strong wind and land cover in dust source regions on the Asian dust event over Japan from 2000 to 2011. Sci Online Lett Atmos 2012;8:77–80.
[37] Lee H, Liu C. Coping with dust storm events: information impacts, and policymaking in Taiwan. TAO 2004;15:5.
[38] Leys J, Heidenreich SK, Strong CL, McTainsh GH, Quigley S. PM_{10} concentrations and mass transport during red dawn. Aeolian Res 2009;3:327–42.
[39] Steenburgh WJ, Massey JD, Painter T. Episodic dust events of Utah's Wasatch Front and adjoining region. J Appl Meteorol Climatol 2012;5(9):1654–69.
[40] Stefanski R, Sivakumar MVK. Impacts of sand and dust storms on agriculture and potential agricultural applications of a SDSWS. IOP Conf Ser: Earth Environ Sci 2009;7:012016.
[41] Wash CH, Murphree T. An analysis of a dust storm impacting Operation Iraqi Freedom. Monterey, California, USA: Naval Postgraduate School; 2004 (March 25–27, 2003).
[42] Xing-liang Z. Damages and countermeasures of catastrophic sandstorm occurred in Gansu province. J Desert Res 1993;13(3):1–7.
[43] Xin-jiang Z, Cheng L, Xiao-ping X. Cloudiness Features of Two Kinds of Dust Devil weather in China. J Meteorol 1995;21(2):27–31.
[44] Ji-xi J. A study of formation for black storm using GMS-4 imagery. Q J Appl Meteorol 1995;6(2):177–84.
[45] Wilkerson WD, Air Weather Service, Scott AFB, IL. Dust and sand forecasting in Iraq and adjoining countries. ; 1991(AWS/TN-91/001, Air Weather Service, Scott AFB, IL).
[46] Hussein AG, Direction and wind velocity surface wind in Iraq [M.Sc. thesis], Basrah University, 2002, p. 140.
[47] McDonald E, Caldwell T. Geochemical and Physical Characteristics of Iraqi Dust and Soil Samples. Final Project Report, Yuma Proving Ground Natural Environments Test Office, October 8, 2004. 〈http://www.defenseindustrydaily.com〉.
[48] King WC, Gilewitch D, Harmon RS, McDonald E, Redmond K, Gillies J, et al. Scientific characterization of desert environments for military testing, training, and operations. United States Army Yuma Proving Ground; 112 (Army Research Office Report).
[49] ASTM (American Society for Testing and Materials), Standard test method for determining the particle size distribution of alumina quartz by laser light scattering, C 1070-86 (reapproved 1992), Annual Book of ASTM Standards, vol. 15, no. 2, ASTM, Philadelphia, PA; 2000, p. 375–6.
[50] Gee GW, Or D. Particle-size analysis. In: Dane JH, Topp GC, editors. Methods of soil analysis: Part 4–physical methods, 5. Madison, WI: Soil Science Society of America; 2002. p. 255–93.
[51] Kelley J. Trip report: collection of soil samples from Iraq, March and April 2004. Vicksburg, MS: ERDC Engineering Geology and Geophysics Branch; 2004; 11.
[52] Anderson J, An analysis of a dust storm impacting operation Iraqi freedom, March 25–27, 2003 [M.Sc. thesis], Department of Meteorology, Naval Postgraduate School; 2004, p. 123.
[53] Nelson DW, Sommers LE. Total carbon, organic carbon and organic matter. In: Sparks DL, et al., editors. Methods of soil analysis: Part 3– chemical methods, 5. Madison, WI: Soil Science Society of America and American Society of Agronomy; 1996. p. 961–1010.
[54] Karathanasis AD, Hajek BV. Elemental analysis by X-ray fluorescence spectroscopy. In: Sparks DL, et al., editors. Methods of soil analysis: Part 3 – chemical methods,, 5. Madison,WI: Soil Science Society of America and American Society of Agronomy; 1996. p. 161–223.
[55] McBride MB. Surface chemistry of soil minerals. In: 2nd ed.. Dixon HB, Weed SB, editors. Minerals in Soil Environments, 1. Madison, WI: Soil Science Society of America; 1989. p. 35–88.
[56] Pye K. Aeolian dust and dust deposits. London: Academic Press; 1987; 334.
[57] Meyers JR, Kumar A, Stephenson LD. Materials selection guide for Army installations exposed to severely corrosive environments. 1996 (Technical Report: ERDC/CERL TR-02-05).
[58] Akhter MS, Madany IM. Heavy metals in street and house dust in Bahrain. Water, Air, Soil Pollut 1993;66:111–9.
[59] Yousif AY. Analysis of air particulates by radioisotopic X-ray fluorescence technique. J Basarh Agric 2007;20(2):29–34.
[60] Al-Ali JT, Study of textural, mineralogical composition and amount of Eolian eposits in Basrah [M.Sc. thesis], Basrah University; 2000, p. 95.
[61] Ahumuda I, Mendoza J, Ascar Z. Sequential extraction of heavy metals in soils irrigated with waste water. Commun Soil Sci Plant Anal 1999;30:1507–19.
[62] Ali HA. Heavy metals concentrations in surface soils of the Haweja area South Western of Kirkuk, Iraq. J Kirkuk Univ Sci Stud 2007;2(3).
[63] Salminen R, Demetriades A. Geochemical atlas of Europe Part 1, background information, methodology, and map. Amsterdam: Elsevier; 617.
[64] Alloway BJ. In: Harrison RM, editor. Soil pollution and land contamination, in pollution: causes, effects and control. Cambridge: The Royal Society of Chemistry; 1995. p. 318.
[65] Asaah VA, Abimbolu FA, Such CE. Heavy metal concentration and distribution in sediment of the Bassa industrial zone, Douala, Cameron. Arab J Sci Eng 2006;31:147–58.
[66] Stanislaw Dudka, Domy C. Adriano. Environment impacts of metal ore mining and processing: a review. J Environ Qual 1997;26:590–602.
[67] Ahmed ZW, Environmental analysis to geographical factors influential in the quantity and quality of fallen air in Thi–Qar Governorate [Ph.D. thesis], Basrah University; 2007, p. 186.
[68] Jassim SZ, Goff JC. Geology of Iraq. Bron: Dolin, Prague and Moravian Museum; 352.
[69] Al-Awadhi JM. Dust fallout characteristics in Kuwait: a case study. Kuwait J Eng 2005;32(2):135–52.
[70] Foda MA, Khalaf FI, Al-Kadi AS. Estamiation dust fallout rates in the northern Arabian Gulf. Sedimentology 1985;32:595–603.
[71] Gasim AA, Asif, MI and Tahir OA, Effect of dust on the leaves and fruits of date palm, Proceedings of second symposium on the date palm. Saudi Arabia, Al-Hass, 1986.
[72] Al-Rayhani AM, Desertification and its effect on utilization of natural resources in Iraq [Ph.D. thesis], Baghdad University; 1986, p. 265.
[73] Al-Sarai DT, DU sites in Iraq, Modern Discussion, vol. 3106, August 26, 2010.
[74] Al-Muqdadi K. Discovery of DU effects is a humanitarian mission. Althakafa Aljadeda Magazine 2000;296:7.
[75] Abulsabor FM. Uranium: uses, effects and its behavior in the environment. Asyot J Environ Stud 2005;29:3 (in Arabic).
[76] Al-Kharouf SJ, Al-Hamarneh IF, Dababneh M. Natural radioactivity, dose assessment and uranium uptake by agricultural crops at Khan Al-Zabeeb, Jordan. J Environ Radioact 2008;102(11):975–1064.
[77] Cheng YS, Kenoyer J, Glissmeyer J. Particle size distribution of aerosols generated inside vehicles. Health Phys 2003;82(6):156–65.
[78] Harley NH, Foulkes EC, Hilborne LH, Hudson A, Anthony CR. A review of the scientific literature as it pertains to Gulf war illnesses, vol. 7, Depleted Uranium. (RAND Report MR-1018/7-OSD).
[79] Burns PC, Finch RJ. Uranium: mineralogy, geochemistry and the environment (reviews in mineralogy), 38. Washington DC, USA: Mineralogical Society of America; .
[80] Bednar AJ, Medina VF, Ulmer-Scholle DS, Frey BA, Johnson BL, Brostoff WN, et al. Effects of organic matter on the distribution of uranium in soil and plant matrices. Chemosphere 2007;70(2):237–47.
[81] Keller MB, Anet BM, Schmid E, Wicki E and Wirz Ch, Depleted uranium: environmental and health effects in the Gulf War, Bosnia and Kosova, Scientific and Technological Options Assessment Series (STOA 100 EN), 2006.
[82] Shahsavania KN, Haghighifardb NJ, Mesdaghinia A, Yunesiana M, Nabizadeh R, Arahamid M, et al. The evaluation of PM_{10}, $PM_{2.5}$ and PM_1 concentrations during the Middle Eastern, Dust (MED) events in Ahvaz, Iran, from April through September 2010. J Arid Environ 2012;77:72–83.
[83] Draxler RR, Gillette DA, Kirkpatrick JS, Heller J. Estimating PM_{10} air concentrations from dust storms in Iraq, Kuwait and Saudi Arabia. Atmos Environ 2001;35:4315–30.
[84] Brunekreef B, Beelen R, Hoek G, Schouten L, Bausch-Goldbohm S, Fischer P, et al. Effects of long-term exposure to traffic-related air pollution on respiratory and cardiovascular mortality in the Netherlands: the NLCS-AIR study; 2009; 5–71 (Research report (Health Effects Institute).
[85] World Energy Outlook Special Report, Iraq Energy Outlook, 9 October 2012.
[86] Ministry of Planning- Republic of Iraq (MOP), National Development Plan for the Years 2010–2014, Ministry of Planning of Iraq, Baghdad, 2010.
[87] Arab Union of Electricity (AUOE), Statistical Bulletin 2010, Issue 19, Arab Union of Electricity, Amman, Jordan, 2010.
[88] IKN (Iraq Knowledge Network), Iraq Knowledge Network Survey 2011, Iraq Central Statistics Organization/Kurdistan Region Statistics Organization/United Nations, Baghdad, 2012.
[89] Brinckerhoff P, Master plan for the KRG Electricity Sector, Parsons Brinckerhoff, Erbil, Iraq, 2009.
[90] Brinckerhoff P. Final report on the survey of private generation in the Baghdad Governorate. Baghdad: Parsons Brinckerhoff; 2009.
[91] Brinckerhoff P. Iraq electricity master plan. Baghdad: Parsons Brinckerhoff; 2010.
[92] Iraq Central Statistics Organization (ICSO), Annual Abstract of Statistics 2010-2011, Central Statistics Organization, Baghdad , 2012. 〈http://www.loc.gov〉
[93] El-khayat MM, Solar energy conservation and photo energy systems: renewable energy potential in the Arab region, 2005.
[94] Landis GA. Mars dust removal technology, In: Proceedings of the IEEE energy conversion engineering conference, NASA Lewis Research Center, vol. 1; 1997, p. 764–7.
[95] Sayigh AAM.. Effect of dust on the flat-plate collectors. In: Proceedings of the international solar energy society congress, New Delhi, India, January 2, 1978.
[96] AL-Hasan Ahmed Y. A new correlation for direct beam solar radiation received by photovoltaic panel with sand dust accumulated on its surface. Sol Energy 1998;63(5):323–33.
[97] Kaldellis JK, Kokala A. Quantifying the decrease of the photovoltaic panels' energy yield due to phenomena of natural air pollution disposal. Energy 2010;35:4862–9.
[98] Kaldellis JK, Kokala A. Simulation the dust effect on the energy performance of photovoltaic generators based on experimental measurements. Energy 2011;36:5154–61.
[99] Mekhilefa S, Saidurb R, Kamalisarvestani M. Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. Renew Sustain Energy Rev 2012;16:2920–5.
[100] Beattie Neil S, Moir Robert S, Chacko Charlslee, Buffoni Giorgio, Roberts Simon H, Pearsall Nicola M. Understanding the effects of sand and dust accumulation on photovoltaic modules. Renew Energy 2012;48:448–52.

[101] Mani M, Pillai R. Impact of dust on solar photovoltaic (PV) performance: research status, challenges and recommendations. Renew Sustain Energy Rev 2010;14(9):3124–31.
[102] Alwan AA, The effect of dust storms on total solar radiation rates for Baghdad city, Iraqi Information Agency (IIA), 2012.
[103] Al-Rasoul KT, Ali FH, Ali MM, Al-Shakry AJ. Characterization of quartz and calcite particle size presents in local dust fell on Baghdad on June 2009. Iraqi J Phys 2010;8(12):60–4.
[104] Ferg EE, Loyson P, Gromer G. The influence of particle size and composition on the quantification of airborne quartz analysis on filter paper. Ind Health 2008;46:144–51.
[105] Wang AS, Angel SJ, Chaney RL, Delorme TA, Reeves RD. Soil PH effects on uptake of CD and Zn by Thlaspi caerulescene. Plant Soil 2006;281:325–37.
[106] Kasim KN, Al-Wattar AJ, Abbas KK. New technique for treatment of the dust accumulation from PV solar panels surface. Iraqi J Phys 2010;8(12):54–9.
[107] Jenkins PP, Landis GL, Krasowski MJ, Wilt DM Greer LC, Status of the dust accumulation and removal technology experiment for the mars. The Fifth international conference on mars. Ohio Aerospace Institute, MS-302-1, 22800 Cedar point Rd., NASA Glenn Research Center MS-77-1, 2001, 〈http://ntrs.nasa.gov〉.
[108] Al-Douri AJ. The electric energy generation approach of the energy saving house using photovoltaic system. Iraqi J Phys 2011;9(15):86–93.
[109] Kubba ZM. Measuring the effect of cell mismatch on PSPICE module model output. Baghdad Sci J 2010;7:3.
[110] Al-Najjar HMT. Experimental evaluation of the performance of one-axis daily tracking and fixed PV module in Baghdad, Iraq. HMT Al-Najjar J Eng 2013;19(9):1145–57.
[111] Al-Douri AAJ, Alias MFA, Alnajjar AA, Alsabounchi AM. Stand-alone PV generator comparing with conventional systems for electrification of small social centers in remote area. Iraqi J Phys 2011;9(15):41–8.
[112] Kubba ZM, Samair Z. PSPICE model of the PV panel. J Al-Nahrain Univ 2009;12(3):51–5.
[113] Kubba ZM, Samair Z. Design and simulation two input converter and testing the PV panel PSPICE model. J Al-Nahrain Univ 2010;13(2):136–46.
[114] Nimmo B, Saed SAM. Effects of dust on the performance of thermal and photovoltaic flat plat collectors in Saudi Arabia: preliminary results. Altern Energy Sour 1979;2:145–52.
[115] Sayigh AAM, Effect of dust on flat plate collectors. Sun, mankind's future source of energy. In: Proceedings of the international solar energy society congress; 1978, p. 960–4.
[116] Said SAM. Effects of dust accumulation on performances of thermal and photovoltaic flat-plate collectors. Appl Energy 1990;37:73–84.
[117] Alamoud ARM, Performance evaluation of various photovoltaic modules in hot and arid environment. In: Proceedings of the 28th intersociety energy conversion engineering conference (American Chemical Society); 1993, p. 2485–90.
[118] Hasan A, Sayigh AA, Effect of sand and dust accumulation on the light transmittance, reflectance, and absorbance of the PV glazing. In: Proceedings of the 2nd world renewable energy congress on renewable energy: technology and the environment; 1992, p. 461–6.
[119] Wakim F. Introduction of PV power generation to Kuwait. Kuwait: Kuwait Institute for Scientific Research; 1981 (Report no. 440).
[120] Sarver T, Al-Qaraghuli A, Kazmerski LL. A comprehensive review of the impact of dust on the use of solar energy: history, investigations, results, literature, and mitigation approaches. Renew Sustain Energy Rev 2013;22:698–733.
[121] Hegazy AA. Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors. Renew Energy 2001;22(4):525–40.
[122] Solar Iraqi Research Group (SIRG), Dust removal technology for solar panels, In: Proceedings of the renewable energy conference: supporting sustainable development for Iraq, Baghdad, Iraq, May 2–4, 2011.
[123] Lee CJ, Zhang SC, JudithX Y, Chow C, An ZS, Ho KF, et al. Characterization of airborne carbonate over a site near Asia dust source region during spring 2002 and its climatic and environmental significance. J Geophys Res 2005;110:D03203.
[124] Sims RA, Biris AS, Wilson JD, Yurteri CU, Mazumder MK, Calle CI et al.. Development of transport self cleaning dust shield for solar panels. In: Proceedings of the ESA-IEEE joint meeting on electrostatics, Little Rock, AR; 2002, p. 814–21.
[125] Dihrab SS, Sopian K. Electricity generation of hybrid PV/wind systems in Iraq. Renew Energy 2010;35:1303–7.
[126] Al-Sudany AHS. Studying the effects of dust and temperature on the solar cell performance [M.Sc. thesis], Al-Mustansiriyah University, 2009.
[127] Astaw KS. Tropical area is a best place to achieve the best performance of amorphous silicon photovoltaic. Leicestershire: Department of Electronic and Electrical Engineering, Loughborough University; 2007 (LE113TU, UK, TPSDP Research Fellowship (TPSDP-ADB) No.1792-INO).
[128] Sabah Kutaiba, Faraj Sabah N. Self-cleaning solar panels to avoid the effects of accumulated dust on solar panels Transmittance. Int J Sci Res (IJSR), 2013;2(9):246–8.
[129] Zhang H, Wang W, Liu R, Zhang J Zong G, Locomotion realization of an autonomous climbing robot for elliptic half-shell cleaning. In: Proceedings of the 2nd IEEE conference on industrial electronics and applications (ICIEA 2007); May 23–25, 2007, p. 1220–5.
[130] Hayakawa M, Kojima E, Norimoto K, Machida M, Kitamura A, Watanabe T, et al., Method for photcatalytically rendering a surface of a substrate superhydrophilic, a substrate with hsupergydrophilic photocatalytic surface, and method thereof, US Patent 6013372; September 19, 2000.